

1. An apparatus for efficiently deflecting light from an optical fiber around a corner, comprising:

a non-imaging optical waveguide, connected to said first port, and adapted to direct light around said corner; and

a second port connected to said non-imaging optical waveguide.

a non-imaging optical concentrator for delivering a beam of light having half-angle divergence of 90 degrees, connected between said optical fiber and said first port.

a second non-imaging optical concentrator, its high-divergence side connected to said second port.

4. The apparatus of claim 1 wherein said second port is adapted to direct light from said optical fiber to a patient, and further comprising:

a third port adapted to be coupled to a second optical fiber and direct light to said second optical fiber with divergence angles of less than 90 degrees from the axis of said second optical fiber;

a second non-imaging optical waveguide, connected to said third port, and adapted to direct light around a corner; and

a fourth port connected to said second non-imaging optical waveguide and configured to receive reflected light from said patient.

5. The apparatus of claim 2 wherein said non-imaging optical waveguide comprises a curved reflective segment connected between said first port and said second port.

6. The apparatus of claim 5 wherein, in any section parallel to the plane of the bend, said curved reflective section appears as an arc of a circle.

7. The apparatus of claim 5 wherein said curved reflective segment is an inner curve, further comprising a second curved reflective segment as an outer curve.

8. The apparatus of claim 1 wherein:  
every section parallel to the plane of the bend is identical, and  
upper and lower surfaces of said non-imaging optical waveguide are planar reflective surfaces.

9. The apparatus of claim 6 wherein said arc has a radius of the width of said first port, and a center at an end of said first port at an inside of said turn around said corner.

10. The apparatus of claim 9 wherein said arc extends to said second port at an angle of 60 degrees from a plane of said first port.

11. The apparatus of claim 9 wherein said arc extends to said second port at an angle not exceeding  $(90^\circ + \phi)/2$ , where  $\phi$  is the maximum half-angular divergence of rays entering said first port.

12. The apparatus of claim 1 further comprising:  
a non-imaging optical concentrator for delivering a beam of light having half-angle divergence of 90 degrees, connected between said optical fiber and said first port;  
and

wherein said non-imaging optical waveguide comprises a first curved reflective segment extending along an outside of a turn around of said corner, and a second curved reflective segment extending around an inside of said turn around said corner.

13. The apparatus of claim 12 wherein, in any section parallel to the plane of the bend, said first curved reflective segment appears as a section of a first ellipse and said second curved reflective segment appears as a section of a second ellipse.

14. The apparatus of claim 13 wherein  
said first ellipse has foci at ends of said second curved reflective segment; and  
said second ellipse has foci at ends of said first curved reflective segment.

15. The apparatus of claim 14 wherein:  
every section parallel to the plane of the bend is identical, and  
upper and lower surfaces of said non-imaging optical waveguide are planar reflective surfaces.

16. The apparatus of claim 14 wherein:  
said non-imaging optical concentrator is of the 3D type, and  
in every section parallel to the plane of the bend, said first curved reflective segment is of such size as to contact the outer edge of said first port and said second curved reflective surface is of such size as to contact the inner edge of said first port.

17. The apparatus of claim 1 wherein said non-imaging optical waveguide comprises:

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a first reflective segment extending along an inside of a turn around said corner from said first port to said second port, such that in any section parallel to the plane of the bend, said first reflective segment appears as a straight line; and

a second reflective segment extending along an outside of said turn around said corner from said first port to said second port, such that in any section parallel to the plane of the bend, said second reflective segment appears as a curve comprising

a first parabolic segment extending from said first port,

an elliptical segment extending from said first parabolic segment, and

a second parabolic segment extending from said elliptical segment to said second port.

18. The apparatus of claim 17 wherein:  
every section parallel to the plane of the bend is identical, and  
upper and lower surfaces of said non-imaging optical waveguide are planar reflective surfaces.

19. The apparatus of claim 17 wherein:  
said first port is circular in cross section, and  
in every section parallel to the plane of the bend, said first curved reflective segment is of such size as to contact the outer edge of said first port and said second curved reflective surface is of such size as to contact the inner edge of said first port.

20. The apparatus of claim 17 wherein said elliptical segment is so constructed that the slope of said elliptical segment is equal to slopes of said first and second parabolic segments at their respective points of intersection.

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1 21. The apparatus of claim 17 wherein said elliptical  
2 segment has foci at the ends of said first reflective segment.

1 22. The apparatus of claim 17 wherein said first  
2 parabolic segment has a focus at an intersection of said planar  
3 reflective segment and said second port.

1 23. The apparatus of claim 17 wherein said second  
2 parabolic segment has a focus at an intersection of said first  
3 reflective segment and said first port.

1 24. The apparatus of claim 17 wherein said second port  
2 is at an angle of less than ninety degrees from said first port,  
3 and further comprising:

4 a third port around a second corner from said second  
5 port;

6 a third reflective segment extending along an inside of  
7 a turn around said second corner from said second port to  
8 said third port, such that in any section parallel to the  
9 plane of the bend, said third reflective segment appears as  
10 a straight line; and

11 a fourth reflective segment extending along an outside  
12 of said turn around said second corner from said second port  
13 to said third port, such that in any section parallel to the  
14 plane of the bend, said fourth reflective segment appears as  
15 a curve comprising:

16 a third parabolic segment extending from said  
17 second port,

18 a second elliptical segment extending from said  
19 third parabolic segment, and

20 a fourth parabolic segment extending from said  
21 second elliptical segment to said third port.

1 25. The apparatus of claim 1 wherein said first and  
2 second ports are rectangular.

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1 26. The apparatus of claim 1 wherein said first and  
2 second ports are circular.

1 27. An apparatus comprising:  
2 a first optical fiber;  
3 a first port coupled to said first optical fiber;  
4 a first non-imaging optical waveguide, connected to  
5 said first port, and adapted to receive light with  
6 divergence angles up to the maximum angle which can  
7 propagate with low loss in said first fiber optic around a  
8 90 degree corner;  
9 a second port connected to said non-imaging optical  
10 waveguide to direct light to a patient;  
11 a second optical fiber;  
12 a third port coupled to said second optical fiber;  
13 a second non-imaging optical waveguide, connected to  
14 said third port, and adapted to direct light around said 90  
15 degree corner to said second optical fiber with divergence  
16 angles up to the maximum that can propagate with low loss in  
17 said second optical fiber; and  
18 a fourth port connected to said second non-imaging  
19 optical waveguide and configured to receive reflected light  
20 from said patient.

1 28. An optical beam delivery system comprising at  
2 least one optical fiber and a non-imaging corner turner according  
3 to claim 1.

1 29. An optical beam delivery system comprising at  
2 least one optical fiber and a non-imaging corner turner according  
3 to claim 27.

1 30. An optical beam delivery system according to claim  
2 28, in which said non-imaging corner turner is integrally molded  
3 upon an end of said optical fiber.

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1 31. An optical beam delivery system according to claim  
2 29, in which said non-imaging corner turner is integrally molded  
3 upon an end of said optical fiber.

1 32. A method for designing a 3D non-imaging corner  
2 turner, said corner turner having an input port and an output  
3 port, and having an intended range of angles of output light rays  
4 comprising the steps of:

5 selecting an initial geometry for said 3D non-imaging  
6 corner turner such that every section of said corner turner in a  
7 plane parallel to the plane of the bend is approximately  
8 equivalent to an in-plane section of a 2D non-imaging corner  
9 turner; and

10 optimizing said corner turner, further comprising the  
11 steps of:

12 computing a merit function for said corner turner, said  
13 merit function comprising a measure of the fraction of optical  
14 power entering said input port which is delivered to said output  
15 port within said intended range of output ray angles;

16 adjusting the corner turner geometry based upon results  
17 of computing step; and

18 successively applying the computing and adjusting steps  
19 until an optimal non-imaging corner turner geometry is reached.

1 33. The method of claim 32 wherein said measure is a  
2 fraction of light rays entering said input port which are  
3 delivered to said output port within said intended range of  
4 output ray angles.

1 34. An apparatus for efficiently deflecting light from  
2 an optical fiber around a corner, comprising:

3 an afferent light guide having a core;

4 a corner turning optical structure;

5 an interface defined between said afferent light guide  
6 and said corner turning optical structure, forming a corner  
7 turner side and an afferent light guide side, and

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8 a defined special angle of incidence measured from a  
9 normal to said interface, said interface having a special  
10 property of reflecting with high probability any light rays which  
11 strike it from a corner turner side, if such rays exceed said  
12 defined special angle.

1 35. The apparatus of claim 34 wherein said core of  
2 said afferent light guide has a first refractive index,  $n_1$ , and  
3 said corner turning optical structure is comprised of a body of  
4 material having a second refractive index,  $n_2$ , wherein  $n_2$  is  
5 greater than  $n_1$ .

1 36. The apparatus of claim 34 wherein said special  
2 property is caused by Total Internal Reflection (TIR).

1 37. The apparatus of claim 34 wherein a single-layer  
2 or multi-layer dielectric coating is applied at said interface,  
3 whereupon an optical interaction between said coating and said  
4 afferent light guide and said corner turning optical structure  
5 causes said special property.

1 38. The apparatus of claim 34, further comprising an  
2 efferent light guide, and

3 a second interface defined between said efferent light  
4 guide and said corner turning optical structure to form a corner  
5 turner side and an efferent light guide side,

6 said second interface having a second defined special  
7 angle of incidence measured from a normal to said second  
8 interface,

9 said second interface having a second special property  
10 of reflecting with high probability any light rays which strike  
11 it from the corner turner side, if such rays exceed said second  
12 defined special angle.

1 39. The apparatus of claim 38, wherein said second  
2 special property is caused by Total Internal Reflection (TIR).

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1           40. The apparatus of claim 38, wherein a single-layer  
2 or multi-layer dielectric coating is applied at said second  
3 interface, whereupon an optical interaction between said coating  
4 and said efferent light guide and said corner turning optical  
5 structure causes said second special property.

1           41. The apparatus of claim 38, wherein said efferent  
2 light guide has a core having a refractive index  $n_3$  and said  
3 corner turning structure has a refractive index of  $n_2$ , where  $n_2$  is  
4 greater than  $n_3$ .

1           42. An apparatus for deflecting light around a corner  
2 while conserving étendue, comprising:

3           an afferent optical light guide for delivering an  
4 afferent beam of light at a maximum divergence half-angle less  
5 than 90 degrees,

6           a non-imaging optical corner-turning structure having  
7 an exit port adjoining said afferent optical light guide to form  
8 an interface,

9           said corner-turning structure and said interface being  
10 adapted to prevent light entering said corner-turning structure  
11 from returning to said afferent optical light guide.

1           43. The apparatus of claim 42 wherein said corner-  
2 turning structure further comprises a plurality of reflective  
3 optical surfaces which direct light to pass through said exit  
4 port operative to prevent light return.

1           44. The apparatus of claim 42 wherein said corner-  
2 turning structure and said interface achieve said prevention of  
3 light return by utilizing angle-dependent reflection properties  
4 of said interface.

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1           45. The apparatus of claim 44 wherein said interface  
2 transmits most rays of said afferent beam, but reflects most rays  
3 incident from said corner turning structure.

1           46. The apparatus of claim 45 wherein said angle-  
2 dependent reflection properties of said interface are achieved by  
3 Total Internal Reflection (TIR).

1           47. The apparatus of claim 45 wherein said angle-  
2 dependent reflection properties of said interface are achieved by  
3 a thin-film dielectric coating, said coating having an angle-  
4 dependent reflective behavior.

1           48. An apparatus for directing around a corner a beam  
2 of light, said beam having divergence half-angle of 90 degrees or  
3 less, while conserving étendue, comprising:

4           a first port adapted to receive said beam of light,  
5           a non-imaging light guide, connected to said port, and  
6 adapted by means of a bend to direct said beam of light around  
7 said corner,

8           a second port connected to said non-imaging light  
9 guide,

10           wherein said non-imaging light guide comprises a first  
11 curved reflective segment extending along an outside of a turn  
12 around said corner, and

13           a second curved reflective segment extending around an  
14 inside of said turn around said corner,

15           wherein in any section parallel to a plane drawn  
16 through the bend, said first curved reflective segment appears as  
17 a first elliptical section and said second curved reflective  
18 segment appears as a second elliptical section.

1           49. The apparatus of claim 48 wherein every section of  
2 said apparatus parallel to the plane of the bend is identical and  
3 wherein said non-imaging light guide further comprises an upper

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4 surface and a lower surface wherein said upper surface and said  
5 lower surface are planar reflective surfaces.

1 50. The apparatus of claim 48, wherein in every  
2 section parallel to the plane of the bend, said first curved  
3 reflective segment is of such size as to contact said first port  
4 at an outer edge and said second curved reflective surface is of  
5 such size as to contact said first port at an inner edge.

1 51. The apparatus of claim 2 wherein said non-imaging  
2 optical concentrator is a compound parabolic concentrator.

1 52. The apparatus of claim 12 wherein said non-imaging  
2 optical concentrator is a compound parabolic concentrator.

1 53. The apparatus of claim 16 wherein said non-imaging  
2 optical concentrator is a compound parabolic concentrator.

1 54. The apparatus of claim 3 wherein said second non-  
2 imaging optical concentrator is a compound parabolic  
3 concentrator.

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